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# Seismic upgrading of frame structures with a soft first story by using hysteretic dampers


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## Abstract

Soft stories constitute a major reason for building collapses during severe earthquakes. The present study investigates a solution for the seismic upgrade of existing reinforced (RC) concrete frames with open first story and masonry infills at the upper stories. It combines the addition of hysteretic dampers with the strengthening of the columns of the first story. The energy-based design procedure put forth provides the strength, stiffness and energy dissipation capacity required for the dampers so that the overall structure can endure the design earthquake without exceeding a prescribed maximum drift at the first story. Finally, using the code for Inelastic Dynamic Analysis of Structures (IDARC-2D), non-linear dynamic analyses are carried out to evaluate the seismic performance of the retrofitted structures and to validate the proposed procedure, the results obtained show that the proposed solution is feasible.


## Introduction and Objective

Frame structures with open first stories and masonry infills at the upper stories are common in earthquake-prone areas all around the world. It is a very attractive solution from the architectural point of view because it allows for large openings to harbor commercial activities, or space for parking. However, it introduces a sudden discontinuity in the lateral strength and stiffness along the height that can result in severe damage concentration. Due to this seismic deficiency many buildings with soft ground story collapsed in past earthquakes (e.g., *Northridge-1994, Hyogoken-Nanbu-1995, etc.*). *Figure 1* shows the schematic solution proposed in this work. The main objective of this study is to achieve a structure able to dissipate most of the energy input by the earthquake in the first story, approaching the behavior of the base isolation systems.

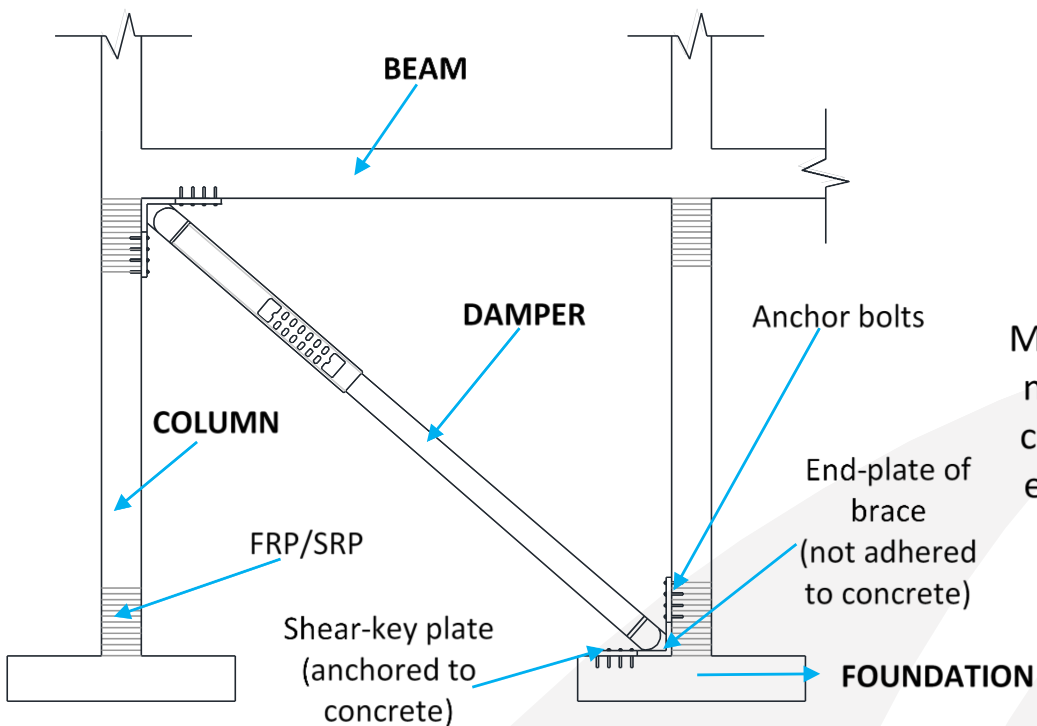



**Figure 1**: Proposed solution schema, steel hysteretic damper and FRP/SRP.

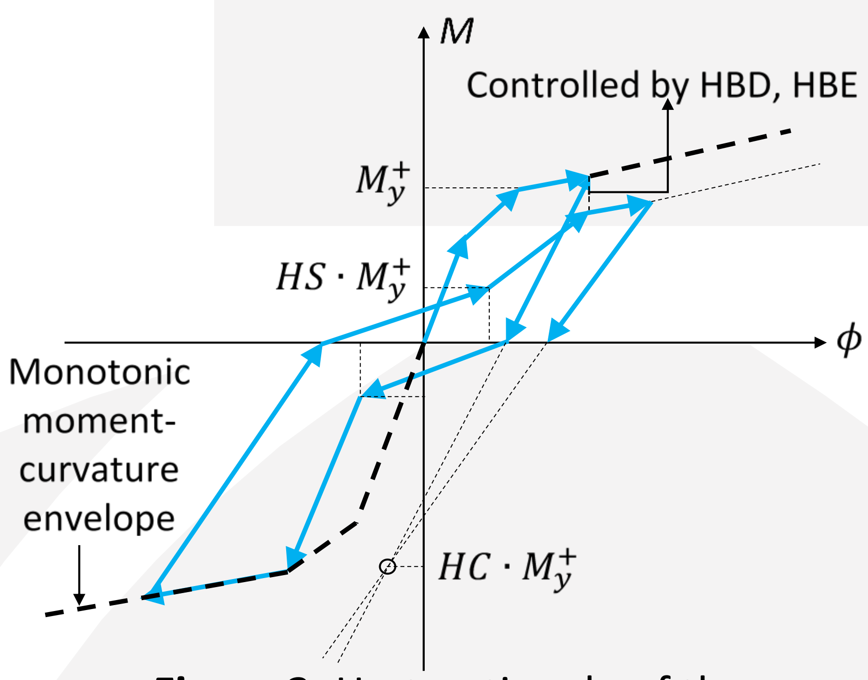
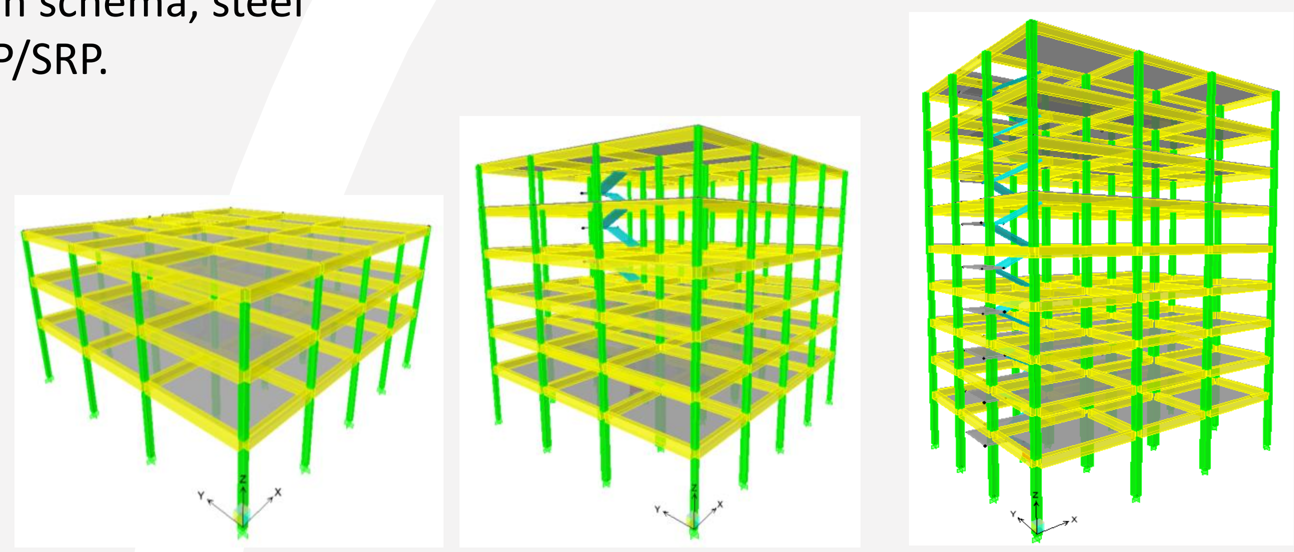



**Figure 3**: Hysteretic rule of the plastic hinges.

## Methodology

To achieve the main goal, several numerical models representing existing RC frames buildings with 3 (N3), 6 (N6) and 9 (N9) stories (*Figure 2*) where developed using IDARC-2D code. Beams and columns are modeled as 2-node frame elements with plastic hinges that concentrate the non-linear behavior at both ends. A graphical representation of the plastic hinge hysteretic rule is shown in *Figure 3*. Next, a simple method to design the proposed seismic upgrading solution is outlined. The method is based on the theory of energy balance of Housner-Akiyama. Finally, the three models developed were subjected to thirty natural accelerograms corresponding to far field earthquakes. Their 5% damped elastic response acceleration spectra are shown in *Figure 4*. The ground motions are selected from PEER and LIS ground motion database respectively.



(a) N3 (b) N6 (c) N9

**Figure 2**: 3D view of prototype buildings

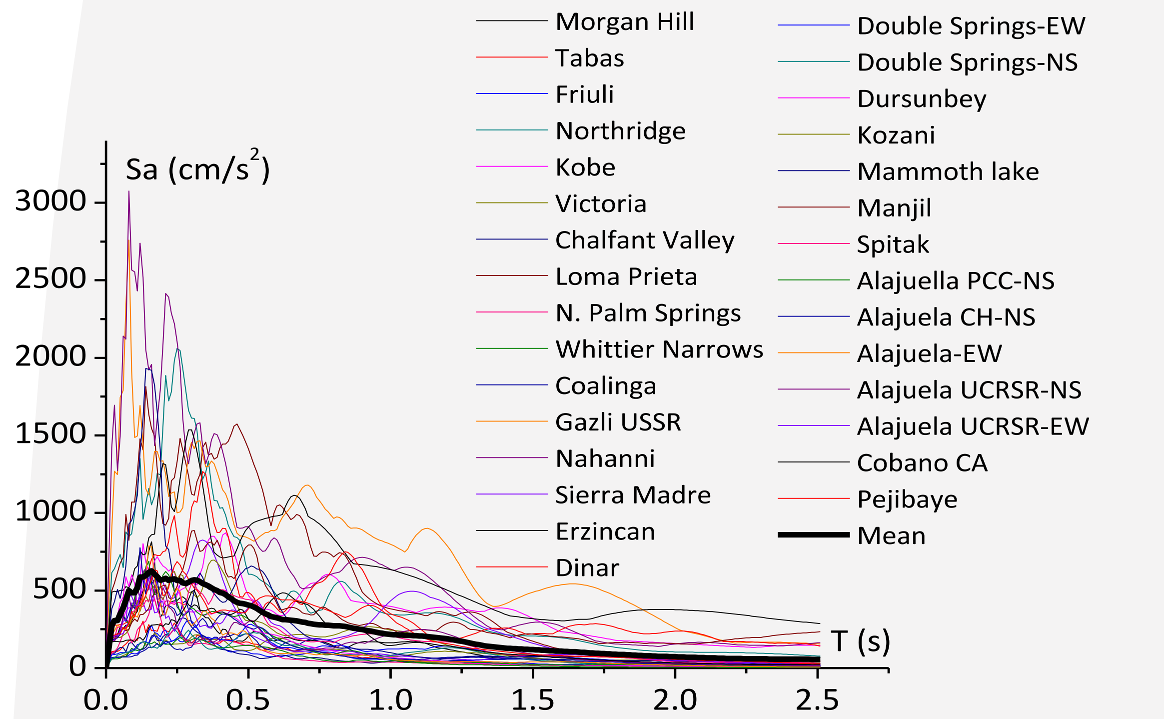



**Figure 4**: Elastic response spectra of non-impulsive ground motions

## Results

Figures *5-7* show the response of the 3, 6 and 9 story prototypes respectively, in terms of the maximum inter-story drift ($\delta_{max,i}$), expressed as ratio of the maximum inter-story drift at story $i$ to the corresponding story height ($MISDR, i$). It can be seen in Figures *5-7* that the $MISDR, i$ remain within acceptable limits. Within these limits, the damage in the RC columns is negligible. The cumulative distribution function (CDF) was obtained by assuming a log-normal distribution of the maximum inter-story drift ratio. It can be seen that the probability of $MISDR$ at the first story being smaller than the design value is about 91%, 81% and 67% for prototype N3, N6 and N9 respectively.

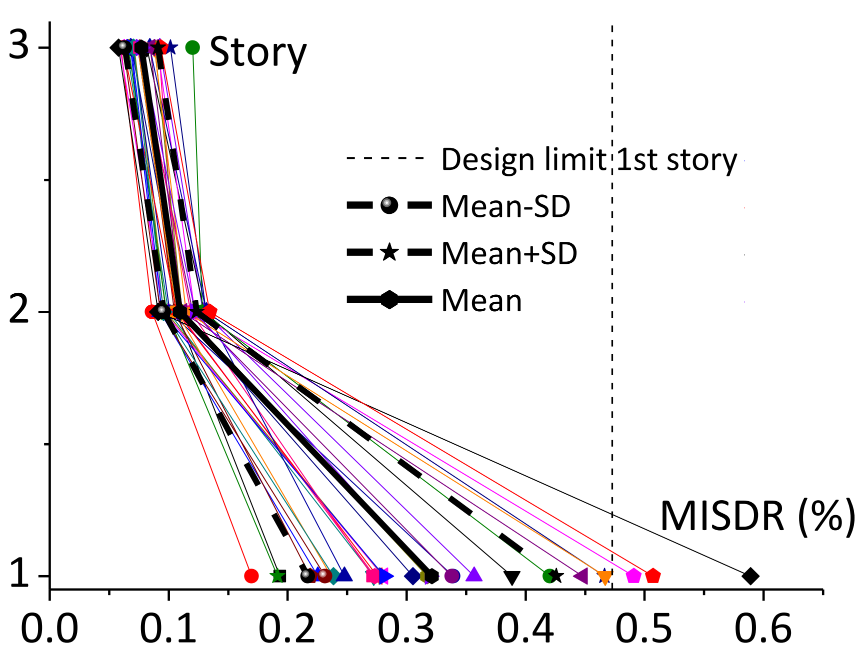



**Figure 5**: MISDR for 3 story prototype

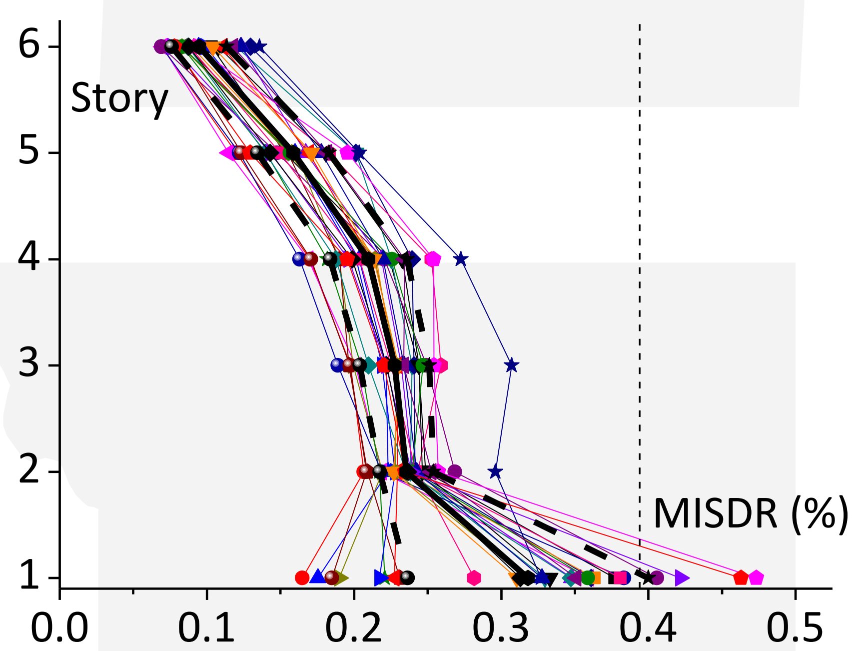



**Figure 6**: MISDR for 6 story prototype

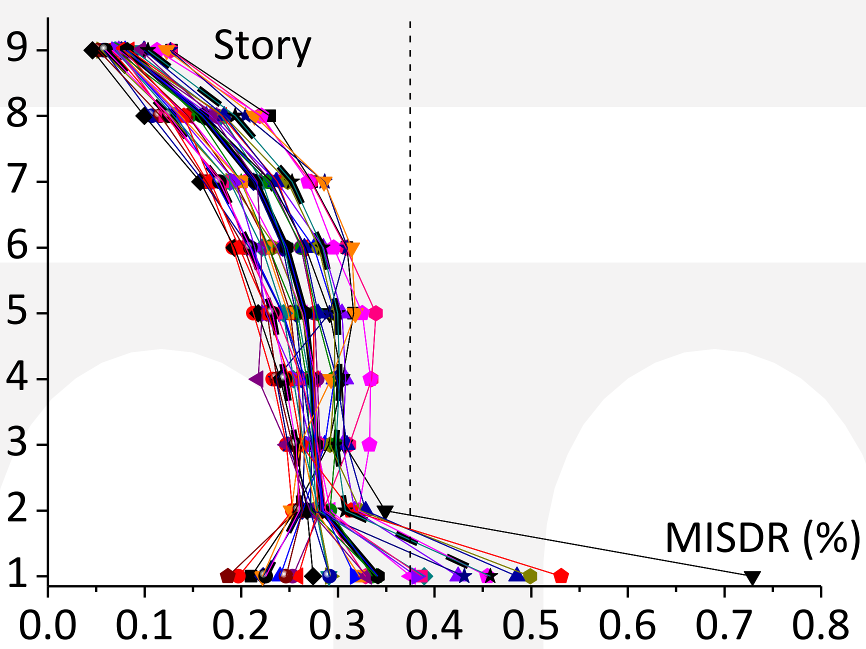



**Figure 7**: MISDR for 9 story prototype

## Conclusions

This investigation proposed a new retrofitting solution and a method for designing and checking the main frame, that protects satisfactorily the existing structure and prevents damage under severe earthquakes in both, first story and upper stories. The proposed design method allows for optimal combination of different seismic upgrading strategies (traditional with composite materials and innovative with energy dissipators).